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Studies on Phagocata Gracilis (Leidy)

By LEON D. PEASLEE, A.M.
ASSISTANT IN ZOOLOGY, UNIVERSITY OF CINCINNATI

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PHAGOCATA GRACILIS (Leidy)

In connection with certain problems in Phagocata, upon which I am at work, there have come to light many interesting facts concerning the life history and morphology of the animal, and it is the object of this paper to treat upon these points. The anatomy of the various Planaridae is essentially similar and has been fairly well worked out for the different species by various investigators, to some of whom I shall have occasion to refer. I have found Dr. Woodworth's paper on Phagocata gracilis of great value and interest, but, on account of several important points of conflict between his work and mine, I find it necessary to cover again a considerable amount of the ground over which he has already gone.

I have also received much valuable information concerning the habits and characteristics of Turbellaria, as well as much assistance in interpreting the problems presented by my slides, from Professor M. F. Guyer and Associate Professor H. M. Benedict, of the University of Cincinnati, to whom I wish to extend my most sincere thanks.

Phagocatae are not infrequent in fresh water in various parts of the world. Running streams seem to be their most frequent habitat, but they are found as well in ponds and lakes. They will be observed gliding along the beds of shallow streams, or, as is mostly the case, under stones or leaves which are beneath the surface of the water. At times they may be found in thousands crawling along the sandy bottom of a brook as if migrating.

Phagocata gracilis (Plate I, Fig. 1) is a small, bilaterally symmetrical flatworm, ranging in size from four mm. long and one wide, to thirty mm. long and six wide. The margins of the body are elongated and somewhat parallel, converging a little at the anterior end to mark off the head region, and taper-

ing markedly to a point at the tail end. The body is flattened dorso-ventrally, being flat or even concave on the ventral surface, while the dorsal side is arched to a slight extent. When at rest Phagocatae appear quite varied in form (Plate II, Fig. 17 B). Some individuals retain the above mentioned shape; some become very irregular in outline; others spread out until they are as wide as they are long; while still others curl up into complete balls. In fact no definite rule can be laid down as to how they will appear when quiet, yet ordinarily they will be short, thick, and wide, with wavy edges. It is a common thing to see Phagocatae resting not singly, but in groups of considerable number. They seem to collect on the sides of the aquaria or in a heavy scum of bacteria at the farthest possible distance from the direct light, and will, apparently, often remain there for days.

The *reaction to light* in the case of Planaria and Phagocata is probably not to be considered heliotropic. Almost every action of uneasiness which they show when exposed to strong light is greatly increased when the exposure is sudden. In such a case they apparently seek more mollifying conditions, and thus will collect in the darker parts of the aquarium. They do so, however, not in the direct course laid down by heliotropism (Loeb '06, Chap. VII), but by the same roundabout, zig-zag course which they employ at all other times. Moreover, the place of minimal intensity of light is in many cases (round aquaria) at the sides, and not directly opposite the entrance of the light rays; and several investigators have noted that Planarians more often congregate in these positions than elsewhere. Though frequenting the darker parts of the aquarium for the most part, Planarians are evidently not forced by any reaction to light to remain there, because they are not infrequently found swimming about over the brighter parts.

Loeb ('06, p. 136) has observed these same facts, and in summing them up has distinguished between his general theory of Tropisms and this apparent reaction (*unterschiedsempfindlichkeit*) to direct or intense light, as follows: "There are other forms which react as well upon sudden increase as upon a sudden decrease of the intensity of light, *e. g.* fresh-water Planarians and earthworms. In these forms a sudden increase in the intensity of the light causes restlessness, while the reverse change causes the animals to come to rest. This may lead to

the gathering of the animals in such parts of the vessel as represent relative minima in the intensity of illumination. When such an animal comes from a bright spot to a darker spot it comes to rest ('falls asleep'). In consequence of this fact such a relative minimum must act like a trap in which the animals are caught. The consequence is that the number of animals collecting in such a place must always increase, inasmuch as any animal which gets to such a spot by chance must remain there because its motions cease."

One can perceive how it is quite possible for the animals to be effected by light, and under too irritating conditions to seek darker places, but it is as hard to see how this purely mechanical explanation of Loeb can force the worms to seek the place of minimal intensity of light by the roundabout course which they pursue, as it is to understand how Pearl's ('03, p. 619) "delicately balanced and finely co-ordinated reactions of the organism as a whole" can bring about the same result. We must admit that intensity of light causes uneasiness, and therefore movement which can be conceived of as a "trial and error" attempt to escape the disagreeable conditions. Still we cannot overlook the fact that these movements, however irregular they may be, are the results of certain body systems which are on the whole definitely coordinated, and therefore responsible to a certain degree for the body actions. For this reason it appears that neither the absolutely mechanical nor the definitely coordinated system can, in itself, produce the ultimate moving away from the intense light to darker places and collecting there; and so we are forced to admit that there must be present either other conditions, or some combination of these two.

Coloration varies quite extensively, the young being usually lighter than the older ones. The majority of fullgrown Phagocatae taken fresh from the stream appear almost entirely black. Frequently, however, one may be found which is distinctly brown in color, and once in a great while a pure white or cream-colored one may be discovered. The ventral surface is never as deeply colored as the dorsal side, and in the black specimens it appears a little greenish, while in the brown ones it is of a lighter color than the upper surface. After remaining in the aquarium for some time, scarcity of food and change of environment seem to moderate the density of the color, and they

appear somewhat of a dull greenish black in the majority of cases. The presence of a distinctly colored food in the alimentary tract is often misleading in determining the actual color of the animal, unless one is well acquainted with its food habits (page 19 on digestion). While crawling on the sides of a glass aquarium and viewed against the light, it appears quite translucent, and usually of a brown color. When in this position many of the internal organs are plainly visible (Plate II, Fig. 17a).

The *pigment* is, in general, in the form of minute granules varying in color from brown to green and even black, and is located in irregular patches underneath the epidermis and between the muscle bundles. In many specimens, usually the oldest ones, rhabditi (see page 9) may be found in profuse number scattered so densely throughout the epidermis as to practically replace it. These rods are larger than those found in the younger specimens, and are often of such a dark color that they determine the coloration of the animal.

The body is divided into two distinct regions, namely, the head and trunk. The *head* occupies only a small portion of the whole length of the body, at the most not over a fifteenth. In the extended condition it is approximately straight across the front, and is not as wide as the trunk region. The outer corners sometimes protrude and give the appearance of ears, as is common in Planaria maculata, but in general this is not the case. There are two eyes, which one may see by careful observation without the aid of a lens.

The *trunk*, occupying the remainder of the body, is flexible and non-segmented. It shows very little differentiation to the naked eye except that its sides are somewhat parallel, tapering to a point at the tail, and that a blackish median line is often present down the center of the dorsal surface.

In section the trunk varies in structure according to the location of the cut, but any section will give the general structure. The outer surface is formed of *epidermal cells* which are of the columnar type, but are usually much distorted. The cells of the dorsal surface are as much as twice or three times as long as they are wide and contain large nuclei situated near the base. The presence of the great number of rhabditi between these cells, however, often disfigures them until they appear of numerous shapes, being commonly somewhat fungi-

form, and in this condition the nuclei may be forced to almost any part of the cell (Plate I, Fig. 2, d.ep.). Woodworth finds that the dorsal epithelial cells show a striated appearance, but I have not been able to distinguish this characteristic with any certainty. I have found a few cells which appeared to have striations, but they were in thick sections, and I am inclined to attribute their presence to other causes. The *rhabditi* are peculiar rod-like structures which are secreted by parent cells located in the parenchyma (Plate I, Fig. 2, rh. c.; and Fig. 8, rh.). Several functions have been attributed to them by different authorities. Some claim they are physiologically equivalent to the nematocysts of the Coelenterates, while others think they are similar to glandular secretions. According to Woodworth ('91, p. 20), "The dermal rods are to be considered as condensed secretions arising in sub-hypodermal unicellular glands of ectodermic origin. The rhabditi are being continually cast out of the body and replaced by new ones developed in new parent cells within the body of the parenchyma. The connection of the parent cells with the epidermis is a primitive one, and the rods pass to the exterior by means of the tubular ducts formed by the neck of the elongated cells. The rods lie between the cells of the epidermis; they are slowly soluble in water, and are used by the animal in securing food and for protection."

On the ventral surface the epidermal cells are much more regular than on the dorsal side. They are practically cubical, and the nuclei are arranged regularly near the bases. Rhabditi may be present here in the case of the older specimens, as was mentioned under coloration, but they are fewer in number and are usually perpendicular to the body wall in general. Covering the outer surface of these cells and also those upon the lateral edges of the body, are numerous *cilia*. They are somewhat longer near the edges, and especially so about the mouth and head regions (Plate I, Fig. 2, cil.).

Directly below the epidermal cells is the *basement membrane* (Plate I, Fig. 2, b. m.). In the great majority of cases this membrane is invisible because it does not take stains readily, but commonly its presence can be determined by the clear space between the epidermis and the muscular layer below. Under very high magnification the membrane appears as a clear homogeneous band of tissue of a slight grayish color which, in most cases, is closely attached to the circular muscle layer

below it, but occasionally may be found adhering to the epithelial cells when they have been torn away from the underlying tissue.

The *musculature* of Phagocata gracilis consists of three distinct systems: the circular, longitudinal, and dorso-ventral. The *circular muscles* form a somewhat narrow band of fibers lying directly below the basement membrane to which, as mentioned above, they closely adhere. The juncture formed by the membrane and the circular layer presents practically a straight line, and in no place can I find the circular muscles indenting into the basement membrane as Woodworth has stated. The function of this layer is mainly to elongate the body by contraction of its fibers (Plate I, Fig. 2, d. c. m., v. c. m.).

The *longitudinal muscle band* which rests in contact with the inner surface of the circular layer varies at different parts of the body. In general it consists of large bundles of fibers which project irregularly out into the mesenchyme and also indent the circular band. High power magnification shows that these bundles are further divided into smaller feather-like groups of fibers which in many cases have clearly marked outlines. In general the bundles are irregular in form and appear to connect with the circular layer only at places, thus leaving clear spaces scattered along between them. Within these clear spaces, between the bundles of longitudinal fibers and along their surfaces, and also upon the inner side of the circular muscles, may be found many large nucleated cells and numerous pigment granules. The chief function of the longitudinal muscles is to shorten the length of the body and to bend the extremities upward or downward by contraction of dorsal or ventral bundles respectively (Plate I, Fig. 2, d. l. m., v. l. m.).

The dorso-ventral muscles which form the third and last system are found only in scattered bundles. They traverse the mesenchyme from dorsal to ventral surface and attach either to the inward projections of the longitudinal bundles, or, passing between them, connect with the inner surface of the circular layer. Their function is to narrow the body dorso-ventrally (Plate I, Fig. 2, d. v. m.).

The *mesenchymatous tissue* which makes up the bulk of the body is varied in structure. In the younger specimens it is composed to a great extent of large somatic cells of irreguarl form, each having a well defined nucleus. Somewhat later msto

of these cells seem to break up and form the irregular meshwork of fibers with scattered nuclei, which is most commonly found in sections (Plate I, Fig. 2, mes.). Throughout the entire extent of this tissue irregular cells and cell spaces interlace with the above mentioned fibers. A very distinct series of open spaces seems to be arranged along the dorsal and ventral parts of the so-called "pseudocoele" directly within the longitudinal muscle layer (Plate I, Fig. 2, 3-5, 14-16, s. m. s.). They compose to a great extent the spaces between the projecting bundles of this layer, and are much larger on the dorsal side where the bundles are more conspicuous. In old specimens the rhabditi are found in numerous masses throughout the epidermis and also fill these spaces.

Spermaries which are filled with developing spermatozoa are also scattered throughout this mesenchymatous tissue; they will be discussed later. Yolk glands or at least similar appearing structures may be found at certain seasons. The dorso-ventral muscle fibers may be seen running along in scattered bundles in almost any part of it. Large cells which appear to be the maternal cells of the rhabditi mentioned above are also common. They are mostly globular or somewhat flask-shaped, and in some sections the opening duct may be observed passing upward through the superimposed network of tissue, penetrating the muscular layers, and finally opening to the exterior between the epidermal cells (Plate I, Fig. 2, rh.c.).

Woodworth ('91) has found two systems of *glands* which open to the outside, and my slides show similar structures. One of these systems is located near the genital pore and the other in the head region. The latter arises as two tubes slightly in front of the ovaries. These tubes pass above the brain, and, turning downward, open on the ventral surface close to the anterior end. They are irregular in form, and have numerous swellings in each of which is located a dark-staining homogeneous nodule of tissue. The functions of these two systems are unknown.

The histology of the remaining organs will be considered under separate headings.

Returning again to external conditions, it will be well to consider here the thick, sticky fluid, very disagreeable to the taste, which is secreted by the ectoderm. Under normal conditions this mucus seems to aid the body in moving, and proba-

bly serves for protection and as a method of capturing food as well. When sudden changes in temperature occur, or when the animals are left for some time without food and change of water, this fluid secretion becomes very noticeable. If Phagocatae are placed in a vial, the water soon becomes filled with a fine meshwork of almost colorless threads in and out amongst which they glide at will. When an aquarium is subjected to the abnormal conditions just mentioned, and also often when no apparent change of conditions has taken place, the animals will congregate either individually or in groups upon the under side of the thick bacterial scum at the surface of the water, and, slowly wending backward and forward, secrete a profuse amount of mucus. This, mingling with the scum on the water and the particles of mud gathered in it, soon hardens and forms an effective protection for the individual or individuals within (Plate II, Fig. 20-21).

I had always considered this a method of protection against environmental changes, but it was not until lately that I was able to obtain definite results which prove the case. Specimens going into cysts while in the aquaria were watched, and without exception were found to remain in the same condition for a long period and finally, after several months (often five or six), to gradually decompose and disintegrate. If, however, the cysts were enclosed in very fine wired cages and replaced in the brook from which they had previously been taken, the Phagocatae soon emerged and were apparently in as good condition as when formerly in the stream, except that they were somewhat smaller. The animals make their exit from such cysts by working out through the walls, which are apparently quite penetrable. It is not clear whether or not the openings made in this way remain, but it is certain that the animals often reenter the original jelly-like cyst and become dormant again if the conditions become unfavorable. The name "protective encystment" has been applied to this peculiar characteristic of flatworms.

The power of *locomotion* in Phagocata is fairly well developed considering its low position in the animal kingdom. We find in general two kinds of movement, a smooth gliding motion, and a crawling movement. The first or gliding motion is brought about by the numerous cilia found on the ventral epidermis. In life these may be observed, by careful

manipulation of the microscope, rapidly beating back and fort all along the ventral surface and the lateral edges of the animal. Across the front of the head and upon the lobes the cilia appear to be much longer and move more slowly, beating from the center toward the lobes and backward toward the tail. Woodworth ('91) records finding cilia all over the whole body surface, but my sections show the cilia only upon the ventral and lateral ectodermal cells; they are missing from the dorsal cells. Bardeen ('02) finds a condition similar to this in Planaria maculata, and states that cilia are never found on the dorsal surface. This fact coincides well with the animal's method of movement, in that the secretion in which the cilia beat is given off more profusely from the ventral body wall, and, moreover, the animal glides with its ventral surface against either some solid object or the surface film of the surrounding water. For this reason it is hard to see how cilia on the dorsal surface could be of much aid in the case of movement.

The crawling or looping movement is due entirely to muscular contraction. When upon solid surfaces Phagocatae will often move in this way, especially if there is a scarcity of water or if the current is quite swift. Through a curving-in of the ventral surface of the body, either as a whole or in local areas, suction is effected, and the body is thus held firmly to the surface with which it is in contact. This suction device is used in making the characteristic looping "inch-worm" movement of locomotion, and likewise apparently as a means of holding the animal's body in contact with the under side of the surface film of the water, either when swimming there or when at rest. When disturbed a series of writhing movements occur which are caused by the alternate contraction and expansion of the various muscle systems.

The *mucus secretion* of the ectoderm, mentioned above, seems to be to a considerable extent an aid in locomotion. It is very sticky in nature and adheres immediately to anything with which it comes in contact in the water. The cilia beat rapidly in this medium and inasmuch as it remains stationary, the body is moved forward. A whitish streak of mucus is often seen in the wake of the moving worm. If, when swimming on the surface, it is suddenly dislodged, it will cling by its tail to the surface, or if it is not able to do this it will hang by a slender thread of mucus and slowly sink to the bottom. When several

specimens are placed in a small vial, as mentioned above, they will in a short time have the water entirely filled with interwoven mucus fibers, which, in time, sink and form large masses of slimy material.

The *bodily activity* in all Phagocatae is somewhat periodical. At times during the day they will be seen moving energetically about, and again one may find them grouped and apparently at rest. During the night they appear to be almost constantly in motion.

The method of coming to rest is somewhat peculiar. Pearl ('03) demonstrates it clearly in the case of Planaria, and as it is comparatively the same in the Phagocata I will quote: "The coming to rest is practically always preceded by a period of slower gliding, but all slow gliding is not immediately followed by rest. After a brief period of this slower gliding the worm suddenly stops, and the posterior half of the body remains fixed in precisely the same position. The anterior half of the body is slowly moved about over the bottom from side to side, the head being touched frequently to the bottom or any other solid objects in the neighborhood. The anterior part in this 'feeling' movement moves about the posterior part as a fixed point, the latter very rarely changing its position after it has once stopped. The apparent significance of the 'testing' movements at the time of stopping is that it is a piece of protective behavior."

In making experiments on regeneration, I have noticed several peculiar modifications in the movement brought about by the effect of the operations. Cross-sections at almost any part of the body seem to have but little effect upon the powers of locomotion of the head end. It swims about just as lively as ever, and responds to all the stimuli by which the normal animal is effected. The posterior part seems, on the other hand, to move much slower, and the nearer the cut approaches the posterior end of the body, the slower the movement. This piece is dormant at first, but later it moves at long intervals (providing the cut was not near enough to the tail end to kill it), remaining, however, for the majority of the time curled up in the dark corners of the aquaria and perfectly quiet. One specimen, which generated a second head as the result of an operation, seemed to be impelled to follow each head, and inasmuch as each head had a direction of its own, very little progressive movement was accomplished.

The *digestive system* of Phagocata gracilis as well as that of all other Triclads is a simple sac, opening to the outside in but one place. This opening—*the mouth*— is situated on the ventral surface of the body, usually a little back of the center and upon the median line. It can be seen in living specimens with the naked eye and appears as a very small opening surrounded by a dark ring of pigment (Plate I, Fig. 1, mo.). The opening in itself often does not appear to be as large in diameter as a single pharynx, and yet it can be expanded to a considerable size, even enough to permit more than twenty pharynges to be protruded through it at one time (Plate II, Fig. 17 C).

The mouth, exhibiting a gradual transition of epithelial cells, opens directly into a large chamber, the *atrium*, which contains the pharynges (Plate I, Fig. 11, p.at.). This cavity occupies about the middle third of the entire length of the body and also about one third of the width. At intervals *partitions* appear in it which seem to a certain extent to separate some of the pharynges from one another. These partitions arise as outgrowths of the lateral walls of the atrium, and extend for varying distances out into the cavity, usually inclining toward the mouth opening and joining to both dorsal and ventral walls throughout their entire length. Some gradually swing backward so as to run nearly parallel to the long axis of the body. These partitions serve as a support for the body-walls, and although they separate pharynges from one another, they converge or end in such a way as not to hinder them from reaching the mouth. In many places these partitions have just begun development, and appear as small projections extending out for short distances into the atrium from between the pharynges (Plate I, Figs. 1 and 9, pt.).

Scattered here and there between the pharynges and the partitions may also be found small outpocketings of the walls of the alimentary canal, which extend into the atrial cavity. They often appear in section to be similar to the partitions, but on following out their structure through successive sections they are found to be long conical outgrowths, each forming a blind sac. It has been shown by several writers that in cases of regeneration pharynges develop as outgrowths of the digestive tract, and there appears to be but little doubt that the outgrowths in question will ultimately break through at their outer ends and become functional pharynges (Plate I,

Fig. 1, r. ph.). The fact that the pharynges are constantly increasing in number as the animal grows older would corroborate this conclusion.

The *pharynges* are elongated, very muscular tubes which serve to secure food for the animal. They can, as mentioned above, be protruded to a considerable length from the mouth. The number varies in different individuals, ranging from fourteen to twenty-eight. I have tried to decide, by comparing many specimens, whether or not there is any definite number which can be considered as characteristic of the species, but the range is so varied that it seems almost impossible to come to any conclusion. It is quite certain, however, that the number varies according to the age of the animals, the youngest always having the least and the oldest the most. In regenerating Phagocatae, of course, any number up to the maximum may be found. One pharynx (Plate I, Fig. 1, a.ph.) is almost always larger than the rest, and connects with the alimentary tract at the juncture of the anterior and posterior trunks. The remaining ones enter the posterior tracts along their inner sides (Plate I, Fig. 1, l.ph.), growing smaller as they approach the posterior end of the body.

Each individual pharynx (Plate II, Fig. 31) in itself is highly specialized for its function. Both the muscular system and the cilia serve to draw in food from the outside, and so specialized is the pharynx in this duty that even when removed from the body it keeps up a vigorous swallowing. The end previously serving as the open or mouth end expands to a considerable size, envelops any particles with which it may come in contact, and then by muscular contraction (a sort of peristaltic movement) carries the food through the pharynx, only to be passed out of the other end. Dr. Woodworth has observed the movements of the pharynx when separated from the body and concludes that cilia bring them about, but, in so far as I can determine, nearly all movement under the circumstances is due to muscular contraction. Cilia, however, are present over much of the surface of the pharynx, and no doubt could be the cause of movement to some extent. About the mouth the cilia are much larger and serve to aid in getting food into the opening.

Structurally considered, the pharynx consists of seven layers which are, beginning with the outermost:

1. *External Epithelium* (Plate II, Figs. 22-24, e.ep.);

composed of columnar epithelial cells. Nuclei are usually invisible in the cells of fully grown pharynges except at the proximal end, but they may be observed on other parts of the pharynx. The external surface is almost entirely covered with cilia in the young pharynx except at the extreme proximal end. The cilia are often lost to a considerable extent in older pharynges, where the cells of the epithelium usually become distorted (Plate II, Fig. 23).

2. *Outer Longitudinal Muscle Band* (Plate II, Figs. 22-24, o.l.m.); usually narrow, but near the basal end of the pharynx it becomes much wider.

3. *Outer Circular Muscle Band* (Plate II, Figs. 22-24, o.c.m.); a wide band which has its fibers grouped into bundles arranged in feather-like clusters similar to those found in the musculature of the earthworm.

4. *Connective Tissue Layer* (Plate II, Figs. 22-24, c.t.); a wide zone of connective tissue containing various kinds of cells and muscle fibers. Many nuclei are found scattered throughout, and often numerous large ones adhere closely to the base of the circular muscle layer. A thick layer of nuclei is also found on the inner surface of the connective tissue which rests upon (5) the inner longitudinal muscle band. The transverse muscle fibers are commonly scattered, but they often run in regular bundles which seem, like so many septa, to divide the connective tissue area into several distinct parts.

5. *Inner Longitudinal Muscle Band* (Plate II, Figs. 22-24, i.l.m.); generally narrow but widening near the proximal end of the pharynx.

6. *Inner Circular Muscle Band*(Plate II, Figs. 22-24, i.c.m.); also of the feathery type similar to the external circular band, but so much more closely interwoven that the structure is often lost.

7. *Internal Epithelium* (Plate II, Figs. 22-24, i. ep.); formed of large columnar cells, which near the mouth of the pharynx are usually regular or often conical. Cilia are found lining the lumen for nearly half its distance back from the mouth. They are quite long in the neighborhood of the external opening. Where the cilia are missing the cells become irregular and the nuclei very noticeable.

The *digestive cavity*, as in other flatworms, has but a single opening to the exterior—the mouth. As in all Triclads the

cavity has three main branches, one running forward toward the head, and two passing backward to the tail region, giving the general appearance of a tuning-fork. The juncture of the three branches is about midway between the mouth opening and the head, and at this point enters the largest of the pharynges as mentioned above (Plate I, Fig. 1, a.t.r., l.t.r.). These main trunks give off smaller branches which extend throughout the body, and in this manner the food is distributed. The anterior canal runs forward through the central part of the body, somewhat toward the dorsal surface, and after passing over the brain turns directly downward and ends as a small canal close to the ventral surface. The branches here are much longer than those of the lateral tracts. The lateral tracts pass backward close along the atrial cavity and converge behind the genital pore so as to come close together in the tail region. The branches here are usually more simple than those of the anterior tract, and are found chiefly on the outer side of the two main trunks. In the extreme tail region a few very small tubes may be found outpocketing from the inner side, but these are mostly insignificant.

The prevailing idea according to statements and drawings on Planaridae is that the two posterior branches of the alimentary tract do not connect. In the case of Phagocata, however, I have found several toto mounts, as well as many sections, which show without the least bit of uncertainty a connecting tube from one of the posterior canals to the other in the tail region (Plate I, Figs. 1, 15, c.br.). Whether this transverse branch indicates the existence of a different variety of Phagocata, or whether it is simply a case in which two neighboring branches have by chance been fused end to end, I am at present unable to say.

The structure of the walls of the digestive tract is quite simple. It is composed of a single layer of rather large columnar cells which protrude into the cavity with somewhat irregular amoeboid-appearing surfaces (Plate I, Fig. 2, al.). If killed and sectioned directly after feeding, these cells are profusely filled with the food taken in, which is often in the shape of minute black granules. The nuclei are large, but not so large as many of those found in the mesenchyme, and rest near the bases of the cells. Occasionally there appear, scattered between the intestinal cells, large clear cells or cell spaces which contain

irregular black rods (Plate I, Fig. 2, i.c.s.). The function of the latter is not clear.

The *food* of the Planaridae is mostly animal matter, and the variety is very great. They will vigorously attack almost any kind of worm or insect which can be found in the water, and even while it is still alive will set about to devour it. In the absence of animal foods, small plants such as Diatoms and Bacteria are consumed. If a fly be dropped into an aquarium where there are Phagocatae, only a few minutes will elapse before it will be covered with the little animals. Whether it is by chance they come near the fly, or whether some sense is employed to discover it from a distance, is not evident, but they are certainly aware of its presence before they come in actual contact with it. I have seen them, with ventral side uppermost, gliding along the under surface of the water directly toward a fly, and, although half an inch from it, with numerous pharynges already protruded from the mouth, squirming about, ready to begin work (Plate II, Fig. 17, C). Several instances have been observed in which Phagocatae have devoured one another, but in each case great scarcity of food was the cause, and not any promiscuous cannibalistic habit such as has been found in some worms. The blood which the Phagocata sucks from its prey is often colored, and as a result it may take on a peculiar appearance. The whole alimentary tract may be colored a bright red, which shows up very plainly if the animal happens to be crawling on the sides of the aquarium. Sometimes only certain of the pharynges will obtain the colored food and, in passing it on, that part of the intestine only which is in close contact with these pharynges will be colored, and thus a very striking appearance is given.

In the absence of food Phagocatae can live for varying lengths of time, depending on the condition of the water in which they are confined. Out of eighteen specimens kept in filtered water, only two lived for fifty days. The number began to decrease rapidly after the thirtieth day, and upon careful observation I at last found several of the animals busily devouring one of their companions. On the forty-fifth day but three were left, and during the same night one of these disappeared. Upon the fiftieth day the remaining two, although apparently well supplied with food for some time, secreted about themselves a mucus cyst, and after several weeks seemed to disintegrate

and disappear entirely. In hydrant water the conditions are greatly changed, due to the fact that the animals can obtain a considerable amount of food from the bacterial scums. They seem to be able to live indefinitely in this condition, and the only apparent effect is that they gradually grow smaller, due to the scarcity of food.

As there are no special *respiratory organs* present, all the oxygen absorbed by the Phagocata must be taken in through the body wall. The ectoderm here, as in the case of so many of the lower animals, is said to perform this function. The cilia, so numerous over much of the body, are constantly moving, and will thus keep the water in motion and have fresh oxygen always in contact with the ectodermal cells.

The *nervous system* is composed of a brain, located in the head; two main nerve trunks running parallel to the long axis of the body; and a lateral network of fibers, often considered a second series of trunks.

The *brain* (Plate II, Figs, 25, 26, 27), located toward the posterior part of the head region, is formed by the union of the main nerve trunks. It consists of two lobes, one on either side of the median line, and a dense mass of connecting fibers, which appears, from frontal and transverse sections, to be divided into four bundles. Woodworth ('91, p. 29) mentions only the anterio-posterior division into two commissures (Plate II, Fig. 25) and fails to consider the distinct division into dorsal and ventral parts which is clearly shown in cross-sections (Plate II, Fig. 27). Fig. 26 also shows the beginning of a division into dorsal and ventral parts within the lobe. Each lobe is deeply indented from above and from below by conical projections of what is presumably connective tissue which extend nearly to the center of the mass.

There are two distinct nerve trunks (Plate II, Fig. 26) arising from the anterior half of each brain lobe and extending forward. The upper or dorsal bundle is much the larger and is the only one commonly recorded. It is composed of several collections of fibers, which soon split up and extend to all parts of the head. One comparatively large mass of fibers from this trunk innervates the eye. The lower or ventral bundle arises by two roots from the anterior half of the brain lobe, and runs along the lower surface of the head to which it gives off many small branches.

The two main *nerve trunks* of the body pass out of the posterior part of the brain lobes midway or somewhat toward the dorsal side, but soon curve downward and come to lie close to the ventral surface. They run practically parallel to the lateral walls of the body, passing outside of the atrial cavity and converging again in the tail region. Each trunk in itself is made up of two series of fibers, slightly separated and having many intercrossing branches. The texture of the fibers is not visible under comparatively high magnification. Numerous branches are given off from the main cords, some of which pass inward and interlace with each other or occasionally join near the median line, while others pass outward toward the periphery and are united to a certain extent near the edges of the animal into two series of fibers which are called the marginal or peripheral cords. A considerable amount of the ventral part of the body just within the musculature is filled with a fine network of fibers which branch and unite so as to form a complex system having the peripheral cords as their outer terminals. In the region of the tail this network becomes very noticeable, and especially so about the genital pore (Plate II, Fig. 29, g.p.). This last mentioned system of fibers is the so-called ventral plexus which Woodworth ('91) observed in Planaria abscissa.

Of the *special senses* Phagocatae appear to have at least three, with the possibility of a fourth. Sight, which we will consider first, is but partially developed, in that the animal can only distinguish between light and dark and apparently does not observe solid objects until it comes into actual contact with them. The *eyes* are situated in front of the brain, one being on each side of the median line. Under the microscope they appear to be composed of two parts, an inner black knot of fibers, surrounded by an outer clear space (Plate II, Fig. 28). The inner part is composed of a very dense opaque tissue which in places appears slightly fibrous. It is either oval or slightly crescentic, and is often cup-shaped. It is always located toward the inner part of the clear space, and when in form of a crescent the convex side is toward the median line of the body. The outer or clear part of the eye is marked by the absence of pigment either in its own tissue or that of the body covering about it. Under very high magnification this clear space shows the presence of many fine colorless nerve fibers. A certain part of it is hidden by the dark portion of the eye which gives

it the appearance of a large clear crescent with its horns pointing inward.

The *sense of touch* is probably the most highly developed of all the special senses, the complex ramifications of the nervous system reaching to all parts of the body. Even the slightest mechanical stimulus at almost any point will call forth a direct reaction. The head end is by far the most sensitive, however, and it is by means of this organ that the animal "feels" its way about. Great numbers of fine fibers run from the brain to the surface of the head, forming a large fan-like structure, thus indicating a high development of the tactile sense in this region.

Besides the above-mentioned senses, Phagocatae exhibit the presence of still another special sense. We know that the animals have a very keen selective capacity in that they much prefer some foods to others. Moreover, the recognition of the presence of food while at a distance (which has already been discussed under digestion) shows the presence of a special perceptive mechanism for this function. There is still some doubt as to whether we are to consider these two responses as one and the same or not. It seems probable, however, that the powers of *tasting* and *smelling* are both present in a primitive condition.

Like almost all other low forms, Phagocatae show no apparent recognition of any kind of sound.

Inasmuch as my results on the *reproductive system* of Phagocata gracilis vary so extensively from those of Woodworth ('91) on the same species, and likewise from the general ideas concerning this system in many of the flatworms, I have striven to work it out in great detail.

Phagocatae, like all other Turbellaria except Stenostomum, Microstomum, and Plagiostomum diocum, are hermaphroditic. Although both male and female cells are present in the same individual, self-fertilization must be very rare, if present at all, as the ova and spermatozoa do not mature at the same time in the same individual.

The female reproductive organs (Plate II, Figs. 19, 32, 33) consist of (1) two ovaries, in the anterior part of the body; (2) two oviducts, leading backward and uniting to empty into the muscular tube close to its entrance into the genital atrium; (3) a large, irregularly formed organ called the uterus, resting anterior to and somewhat above the large pear-shaped sperm receptacle; (4) a uterine duct, connecting the uterus with the

genital atrium, which, in turn, opens to the exterior by means of the genital pore; (5) parovaria and yolk glands.

The *ovaries* are two in number and are located in the anterior third of the body, a short distance in front of the first pharynx and immediately central to the longitudinal nerve cords (Plate I, Fig. 6, ov.). They rest close to the ventral surface of the body below the large branches of the alimentary canal. The individual ovary (Plate II, Fig. 19) is a somewhat rounded structure, four or five times the size of the ordinary spermary. It is bounded by a very narrow layer of fibrous tissue which usually adheres so closely to the surrounding connective tissue that it is often overlooked. Various stages of developing ova may be seen within one ovary. Around the outer edges are gathered the earliest stages, and the more mature ova are often scattered loosely within the center of the mass. Oogenesis appears on superficial examination to be similar to that found by Child ('07) in Moniezia, except that as yet no cases of mitosis have been observed. Amitotic divisions are fairly common.

The *Oviducts* are two in number, one opening from the posterior or slightly to one side of each ovary (Plate II, Fig. 19, od.), and passing backward close to the two main nerve trunks. Directly above the region of the genital atrium they unite to form a single duct, which immediately turns downward and empties into the muscular tube of the male genital system a short distance from where this organ enters the genital atrium (Plate II, Figs. 32, 33; Plate III, Figs. 45, 64, od.). The condition here agrees in most respects with that recorded for Planaria alpina and Planaria torva. In these forms the common oviduct is shown as entering the genital atrium at a considerable distance from the opening of the uterine duct, and quite close to the penis (Gamble, '01). In Phagocatae the muscular tube is to be considered as an extension of the genital atrium, and so the similarity is apparent. Woodworth ('91) describes this duct as opening into the vagina (uterine duct) close to its entrance into the genital atrium[1], but in my specimens, at least, this is not the case.

Structurally considered each oviduct is made up of a single

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1. This condition is also given for Planaria polychroa where the oviducts enter the uterine duct separately, and in Gunda ulvae where they enter after uniting (Gamble, '01).

layer of closely set cells surrounded by a delicate basement membrane which seems to rest directly upon the cells of the surrounding mesenchyme (Plate II, Fig. 36).

The so-called *uterus* (Plate II, Fig. 32, 33 ut.), which is the same as that designated by other writers under the same name, is an irregular, often somewhat club-shaped sac lying directly anterior and somewhat dorsal to the sperm receptacle, and occupying the space between that organ and the pharyngeal atrium. It often projects forward into the posterior part of the pharyngeal cavity, as is shown in transverse sections through this region (Plate I, Fig. 11, ut.). Histologically considered the uterus is quite simple, consisting of two layers only. The inner or epithelial lining is composed of rather large, irregular, pyriform cells which are more or less granular, strictly suggesting glandular tissue. The outer layer is a thin structureless band which is continuous with the muscular coat of the uterine duct. As Woodworth ('91) has said, a greater variety of ideas exists concerning the uterus of flatworms than any other structure of the body of these forms. In P. gracilis he finds it to be glandular in structure and also a receptacle for both spermatozoa and ova, and believes that fecundation takes place there. Up to the present time, however, I have been unable to determine the presence of any spermatozoa in the uterus, and in but one preparation have I chanced upon anything which might be taken for developing eggs. In this case two large bodies were present, but because of excess of stain nothing of their structure could be observed.

The fact that no definite eggs have been found within the uterus and also the well proven conclusion that the oviducts in Phagocatae, as well as in several other similar forms, do not empty into the uterine duct at all but instead lead to the genital atrium, have brought up again the old question, does the uterus of the Planaridae function as a receptacle for ova and developing eggs? This question will be discussed more thoroughly in a later paper, but at present it will be well to say that it is difficult to see how the so-called uterus, in Phagocata at least, can serve as such, when one considers the general anatomy of the reproductive system. The eggs in this form, as well as those mentioned above as showing a similar condition, would be obliged to pass from the oviducts into the muscular tube of the male genital system and thence into the genital atrium before entering the uterine duct. The genital atrium is a chamber

connecting directly with the exterior, and therefore the ova must pass almost to the outside of the body and then be withdrawn again by some unexplained power of the uterine duct (that this condition would of necessity follow can be readily seen by a reference to Plate III, Fig. 64). It may be argued that the cilia within the lumen of the uterine duct could bring this about, but when one considers that these cilia are only present in the proximity of the uterus proper and at a considerable distance from the mouth of the duct, it seems improbable that they can be responsible for the withdrawal of the ova from the genital atrium. So it would seem from the above facts that either the function of the so-called uterus in these forms has been radically mistaken or that there still remain other factors, not yet discovered, which will explain how the uterus or its accompanying duct is able to remove the ova from the genital atrium. As a suggestion it might be well to mention here the possibility that this so-called uterus may serve as a receptacle for spermatozoa, as Kennel ('88, p. 458) has found in certain Turbellaria; or, as is suggested by its glandular structure, it may serve as an organ for the secretion of the cocoon, as is recorded by Iijima ('84) in fresh-water Triclads.

The uterus, as already indicated, connects with the genital atrium by means of the *uterine duct*.[1] This passes backward from the uterus close to the dorsal surface, above and to the left of the sperm receptacle, and finally turns directly downward and empties into the genital atrium just to the left of the muscular tube (Plate II, Fig. 32). There is no definite muscular sac here as is shown in Dendrocoelium lactea and Planaria torva. The structure of the uterine duct has been well worked out by Woodworth ('91, p. 36), who says, "Where the vagina arises from the uterus it is lined with a ciliated epithelium of low cubical cells, and possesses a musculature of circular and longitudinal fibers. As it passes backward, the cells of the lining epithelium become taller and cylindrical, and the nuclei are elongated (Plate II, Fig. 34). The outer ends of the cells show distinct granulations, and the contour of the lumen becomes uneven; the granular nature of the cells now becomes apparent. Along with the change in appearance of the cells of the lining epithelium there is an increase in the thickness of the muscula-

1. Woodworth has termed this duct the "vagina."

ture, which now consists of alternating layers of circular and longitudinal fibers. The musculature of the vagina reaches its greatest development at the point where it bends toward the ventral side of the body; from this point onward the cells lose their granular character, and the musculature diminishes in thickness, till, at the point where the vagina receives the oviducts, it again consists of only a single layer each of circular and longitudinal fibers."

The *genital atrium* (Plate II, Fig. 32; Plate III, Figs. 48, 64, g. at.) is a rather small cavity formed by the union of the muscular tube and the uterine duct. It lies close to the ventral surface, to which it opens by means of the *genital pore* (Plate III, Fig. 64, g.p.). The lining is of epithelial cells which show a marked transition between the cubical cells of the ventral epithelium and the long pyriform cells of the muscular tube and uterine duct.

The *yolk glands* (Plate II, Fig. 30) are periodical in their appearance, and it was not until after many attempts that I could find material which corroborated Woodworth in his conclusions concerning them. They first appear near the anterior part of the body as small groups or chains of cells which gradually increase in size and number so as to occupy a considerable space. The individual cells are large and irregular, and contain heavily granulated nuclei. As yet I have not been able to find anything which corresponds definitely to the parovaria mentioned by Woodworth. According to that author a large mass of cells (parovaria), the function of which is to supply material to the yolk glands, is to be found encircling three sides of each ovary. Holding in mind, however, the fact that it took me so long to come to a common conclusion with Woodworth concerning the yolk glands, I have refrained from drawing any conclusions upon the parovaria, which he maintains are closely related to these glands.

The male sexual organs consist of (1) numerous small testes scattered throughout nearly the whole extent of the body; (2) minute, practically unrecognizable spermatic ducts leading from the testes to the vasa deferentia; (3) the two vasa deferentia for collecting the spermatozoa and conducting them to (4) the large muscular sperm receptacle in which are stored the fully developed spermatozoa; (5) the penis, contained in the lower chamber of the sperm receptacle and opening directly into

(6) a large muscular tube which connects with (7) the genital atrium; and (8) the genital pore.

The *testes* (Plate I, Figs. 1-16, sp.) are very numerous and are widely scattered, ranging from directly behind the brain to the tip of the tail. They are found in the mesenchymatous tissue filling in the spaces between the branches of the digestive system, and, though some may be located toward the dorsal side, the great majority are found nearer the ventral surface. This somewhat ventral location of the testes seems to be directly opposed to the general conditions recorded for other flatworms. Woodworth ('91, p. 31) finds that after the mature spermatozoa have found their way to the vasa deferentia all traces of the testes disappear. I have not found this to be the case in my material. Every section that I have made, no matter at what time of the year the material was collected, shows the presence of many testes.

In early stages the testes may be found appearing as small clumps of cells, often not more than two or three in number, which are scattered throughout the mesenchyme. By means of division, which, as in the case of the ova, is apparently amitotic, these few cells multiply and form clumps of comparatively large, highly chromatic cells, which I have concluded are of the spermatogonial type (Plate II, Fig. 18, sp'ga.). Shortly after this stage is reached many cells may be found in which the chromatin has collected into masses which may represent symapsis. Following this, in some cases the granules seem to collect more markedly about the walls, and the cells as a whole become somewhat elongated and barrel-shaped (Plate II, Fig. 18, S-1). This condition seems to be a preparation for an amitotic division which follows. In other cases definite chromosomes (Plate II, Fig. 18) may be seen which divide mitotically. These divisions give rise to large masses of cells which are highly chromatic and evenly granulated (Plate II, Fig. 18, S-2). Following this stage enters a series of divisions which in many cases are apparently amitotic in character and which result in still smaller cells having a clear cytoplasm and large deeply staining nuclei. These are apparently the spermatids (Plate II, Fig. 18, sp'td.), and every stage of intergradation can be found between them and the mature spermatozoon (Plate II, Fig. 18, sp'za.). The nucleus of the spermatid appears to become elongated and pointed at one end, and at this end the tail of

the spermatozoon is formed. The cytoplasm remains surrounding the bulk of the nucleus, but on account of the increase in size of the latter, the cell wall comes to lie so close to it that often all traces of the achromatic tissue are lost. The head of the spermatozoon then elongates markedly, and the cells come to lie in massive clumps about characteristic nurse cells which are located near the center of the spermary. All of the foregoing stages may be found within a single spermary, as is shown in Fig. 18 of Plate II, but on account of the minuteness of the cells I have found it quite difficult to determine the characteristic stages of spermatogenesis.

It has proven practically impossible to trace the course of the spermatozoon from the testes to the vasa deferentia. Many of the spermaries, however, have been found to show elongations of their surrounding walls which become smaller and smaller as they recede from the body of the testes and finally disappear. These in all probability are to be considered the *sperm ducts*.

Lying along the outside of the pharyngeal cavity, on either side, and close to the ventral wall, may be found the two *vasa deferentia* (Plate II, Figs. 32-33, vd.). Each duct originates as a comparatively large tube somewhat near or a little anterior to the mouth, and in passing backward gradually decreases in size until it reaches the region of the uterus. From here it passes still farther on toward the tail end, parallel with the corresponding duct of the opposite side, and finally when close to the apex of the sperm receptacle, turns inward and upward to enter the base of the latter on its lateral surface. This account of the course of the vasa deferentia is directly opposed to that of Woodworth ('91, p. 31), who says, "They (vasa deferentia) run backward parallel to each other until near the base of the penis; they then turn at right angles toward the middle plane, where they unite to form a single tube which terminates at the apex of the penis (sperm receptacle)." Not one of the several hundred specimens which I have prepared shows any exception to the course which I have described for the vasa deferentia, and in no case can I find any trace of these ducts turning at right angles in the vicinity of the "penis" and joining into a single duct to enter the apex of that organ.

It is with regard to the so-called "penis," however, that my observations differ most extensively from those of most other investigators upon the same or allied species. The large

pear-shaped structure which is termed the penis in so many flatworms is present in P. gracilis and is described by Woodworth ('91, p. 32) as being very similar to that of Planaria polychroa: "The penis or intromittent organ is a highly muscular plug-like structure that lies in the genital atrium or penis sheath. It is covered with flattened epithelium, under which there are alternating layers of circular and longitudinal muscles, five of each, forming a thick zone. Immediately outside of the epithelial lining of the tube there is a band of circular muscles, and between these and the outer muscles there is a broad zone occupied by a meshwork of muscular fibers, prominent among which are those having a radial direction. The lumen of the penis is not of an even calibre, but consists of a succession of chambers, or dilations, lined with a granular epithelium, which is probably glandular. . . . . The sheath of the penis is lined with an epithelium of cylindrical cells, the nuclei of which lie close to the bases of the cells, and are stained deeply, while the glandular cell substance is stained only slightly."

The above description agrees, as far as it goes, with my results, except that in the place of the five alternating layers of circular and longitude muscles, I find simply a broad band of muscular tissue which shows but little differentiation. Woodworth has, however, omitted several important details concerning the structure of this organ.

It is evident in Phagocata gracilis, and I am inclined to believe this will be found to be true in many other flatworms, that what is usually called the penis is in reality a large muscular organ which contains within itself both the true penis and certain enlargements for the purpose of storing up mature spermatozoa.

The vasa deferentia do not enter, as described by Woodworth, by a common duct at the base of the "penis," or *sperm receptacle* as I shall term it from now on, but through separate openings on opposite sides of that organ (Plate II, Fig. 33; Plate III, Fig. 50, v.d.). Their points of entrance are quite close to the most anterior extremity, where the muscular tissue of the organ projects forward and attaches to the ventral wall of the body. They pass down through the anterior half of the sperm receptacle, which is composed of irregularly arranged muscular and connective tissue, and, converging so as to lie close to one another, enlarge suddenly to a considerable size,

to finally unite and empty directly into the anterior seminal chamber by a single duct (Plate II, Fig. 33; Plate III, Figs. 53-56, v.d.i.).

The *anterior seminal chamber* (Plate II, Fig. 32,33; Plate III, Figs. 38-43, 53-57, a.c.) is the largest of three chambers which occupy the greater part of the distal half of the muscular sperm receptacle. It begins as a narrow opening close to the dorsal wall of the receptacle about three fifths of the distance from its proximal end. As it passes backward, occasionally a little to one side of the median line, it enlarges until it occupies the greater part of the diameter of the receptacle, and then pinches off into two slender tubes which empty into the posterior seminal chamber (Plate III, Fig. 58, c.).

The posterior seminal chamber (Plate II, Figs. 32-33; Plate III, Figs. 43-59, p. c.) is much like the first, except that it is smaller, and more centrally located. Both of these chambers are surrounded by a clear strip of muscular tissue, and their lumens are lined with an irregularly scattered, granular epithelium. A single duct leads backward from the posterior seminal chamber and is continuous with the lumen of the penis. This duct is quite convoluted, and in sections often appears like several enlargements instead of a continuous tube (Plate III, Fig. 43, d.).

A third chamber (Plate II, Fig. 33; Plate III, Fig. 44, p.s.) is present which at first glance might be mistaken for an additional seminal chamber. It is, however, an extraneous chamber which in reality surrounds the penis, being an invagination of the distal end of the sperm receptacle to form a *penal sheath.* The muscular walls of this chamber are continuous with the external musculature of the receptacle proper and connect by a ligament-like structure (Plate III, Fig. 45, a.) to the walls of the main sheath surrounding the sperm receptacle. This attachment serves as a hold fast which anchors the penal sheath when the penis is protruded.

The *penis* (Plate II, Figs. 32, 33; Plate III, Figs, 44, 60, pe.) is attached anteriorly to the base of the penal sheath by a strong muscular band and is traversed by a single duct which is continuous with the lumen of the posterior seminal chamber. Structurally the penis is composed of a dense muscular tissue and is covered externally by a fine, irregular epithelial layer whose cells give the organ an uneven knotty-appearing surface.

The penis of Phagocata does not at any time turn inside out, as it were, but is an organ of fairly constant form. Protrusion is accomplished by contraction of the walls of the sperm receptacle, which in turn forces the distal end of that organ farther from its point of attachment. Through this contraction the receptacle itself is lengthened, and inasmuch as ligament-like structures bind the walls of the penal sheath tightly to the sides of the main sheath of the receptacle, an evagination of the end of the receptacle results, and thus a protrusion of the penis is accomplished.

Benedict ('00, p. 363) in a fish tapeworm of the Genus Proteocephalus describes the manner in which the cirrus is protruded, and it is quite similar to my observations. "The mechanism for protrusion seems to be as follows: The longitudinal muscles of the cirrus sac, which are reflected at the distal end of the pouch into the walls of the inner tube, by contraction, would evaginate that distal portion of the tube which is free from the cirrus, and pull the rest of the inner tube outward through the sac, stretching the 'roots'. The evaginated distal portion of the tube forms the muscular protuberance, the former rough cuticular lining of which is now on the outside. Retraction would be accomplished principally by the roots, which, as has been seen, are attached to the proximal end of the inner tube."

Benedict also shows a structure in the case of the penis and its associated organs which is much like that I have described for Phagocata gracilis. He says: "The cirrus sac is an elongated oval in shape, slightly constricted in the middle. It extends from the edge of the genital pore to the median dorsal line of the parenchymal space, where a number of heavy muscle strands attach the proximal end of the inner tube of the pouch firmly to the dermo-muscular sac. . . . . At the anterior end the wall of the pouch bends back, forming a tube through the middle of the sac. This tube is lined in the distal half, by cuticula, which is continuous with that covering the surface of the body. . . . . At the proximal end the free cirrus enters a muscular protuberance of the shape of a truncated cone . . . . . The cirrus passes through the center of this and back through the pouch in very intimate connection with the walls of the inner tube of the sac." As may be readily seen from the quotation, the cirrus pouch differs

considerably from the organ I have termed the sperm receptacle, but the penis and its attachment as well as its manner of protrusion is strikingly similar to that found in Phagocata.

Lastly among the male genital organs is the *muscular tube*[1] (Plate II, Figs. 32, 33; Plate III, Figs. 40-47; 53-64, m.s.), which connects the sheath-cavity of the sperm receptacle with the genital atrium. It may spring either directly from the posterior end of the sheath (Plate III, Fig. 45, m.s.) or, more frequently, a considerable distance forward on the ventral side (Plate III, Fig. 54, m.s.). It passes backward to the right of the uterine duct, turns downward, and empties into the dorsal surface of the genital atrium. The structure of the muscular tube is quite similar to that of the uterine duct, except that it is somewhat oval instead of circular in shape and is in nearly all parts considerably larger in diameter.

Regeneration in Phagocata gracilis is not greatly different from that found in practically all the other members of the Planaridae, and as this subject is to be treated in a later paper it will be omitted here.

Biological Laboratory,

University of Cincinnati, March 11, 1910.

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1. The organ which is here termed the muscular tube appears to be an anterior extension of the genital atrium as described by other writers, but because it has been extended into such an elongated tube it has seemed permissible to apply the above-mentioned name.

METHODS

It may be well to mention here some of the methods which have been employed in preparing specimens for investigation.

First of all it is necessary to say that much better results have been obtained in all cases where the animals have been kept confined in clear water, without food, for a few days previous to killing.

Many killing and fixing fluids have been used, the most important of which are: Hermann's, Merkel's, acetic alcohol, Zenker's, Fleming's, formalin, alcohol, Gilson's mercuro-nitric, etc. Of these Merkel's fluid—

Chrom-platinic mixture:

Chromic acid (1% aq. sol.)	25 c.c.
Platinic chloride ($PtCl_4$) 1%	25 c.c.
Distilled water	150 c.c.

and Gilson's

Mercuro-nitric fixing fluid:

Bichloride of mercury	5 g.
Nitric acid (80%)	4 c.c.
Glacial acetic acid	1 c.c
Alcohol (70%)	25 c.c.
Distilled water	220 c.c.

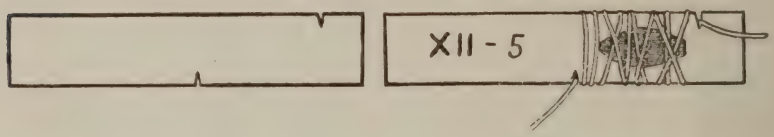
are by far the most satisfactory in working with Phagocata.

The Gilson's mixture is probably the most reliable. It kills and fixes the tissue readily and is followed well by almost any stain. To kill with this fluid it is generally recommended that the mixture be heated, but in the case of Phagocata I find that heat seems to cause a curling, and also the secretion of a dense mucus. Both of these objections are eliminated by simply flooding the slide, upon which an animal is swimming in a few drops of water, with cold Gilson. The animal curls up for a second or two and then gradually straightens out to a perfectly flat condition. At this point a cover-glass is dropped upon the body and the slide cover, worm, and all are immersed in the killing fluid for about ten minutes or longer; thence transferred to 50 per cent alcohol, to which a few drops of iodine have been added in order to remove the excess of mercuric chloride.

For toto mounts Guyer ('06) has offered the following method which has given some good results:

Kill with hot Gilson's,[1] 10-15 min.; wash in 50% alcohol to which a few drops of iodine have been added, 30 min.; stain in weak Borax Carmine or Delafield's Hematoxylin (one of stain to fifteen of water) 24 hrs.; wash in water; decolorize in acid alcohol; dehydrate; flatten by compression between two slides (fasten with rubber bands) and harden for 24 hrs., in 95% alcohol; absolute alcohol 1 hr.; xylol 1 hr. or until clear; mount in Canada balsam.

For sectioning, especially where frontal sections are desired, great difficulty is experienced in keeping the specimens from wrinkling and curling while in the xylol and paraffin. I was practically unable to obtain a complete frontal section of any kind until I hit upon the following simple method. The worm is taken from 95 per cent. alcohol and placed, dorsal surface up, upon a small piece of cardboard about ¼ inch wide by 1¼ inches long, upon the sides of which two small slits have been cut some half an inch apart. A piece of fine thread or pre-



ferably an easily broken raveling from a piece of common cheese-cloth is caught in one of the slits and then wound over and over the entire body of the worm, to the other slit in which the loose end is caught. In this condition the preparation is carried through absolute alcohol, xylol, and the paraffin bath. To imbed, cut along the edge of the cardboard with a pair of sharp scissors (thus cutting all the threads at once) and remove the tissue to the embedding L's.

The paraffin used varies according to the thickness of the sections desired. Hard paraffin (62 degrees) is necessary to get very thin sections, whereas that melting at 45-50 degrees is best for thick topographical sections. Because of the brittleness of the tissue it has been found of great advantage to use Johnson's-Paraffin-Asphalt-Rubber method.[2] The imbedding

1. Cold Gilson has been substituted for the hot in this method.
2. Guyer: *Animal Micrology*, p. 44, or Johnson: *Journal of Applied Microscopy*, Vol. VI, p. 2662.

mass consists of one part of crude India rubber cut into very small pieces, mixed with ninety-nine parts of hard paraffin which has previously been melted and tinged to a light amber color with a small amount of asphalt ("mineral rubber"), and subjected to a temperature of not over 100 degrees for from 24 to 48 hours.

The stains used have been of various kinds, and space permits the mention of only a few of the best. The two most commonly used have been Delafield's Hematoxylin counter-stained with eosin, for general structure, and Heidenhain's Iron Hematoxylin followed by Bordeaux red or Orange G. as a cytoplasmic stain, for more minute details. Van Giesen's Picro-fnchsin is very serviceable in bringing out the muscular system and connective tissue. Lyons blue, gentian violet safranin, carmalum, hemalum, borax carmine, picric acid, acid fuchsin, and many others have been found to be quite tervice-able stains in control material.

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EXPLANATION OF FIGURES

a.	Attachment of sperm receptacle to sheath.
a. c.	Anterior seminal chamber.
a. co.	Anterior commissure.
al.	Alimentary canal.
am.	Amitosis.
a. ph.	Anterior pharynx.
a. tr.	Anterior intestinal tract.
b. m.	Basement membrane.
br.	Brain.
c.	Connection between anterior and posterior seminal chambers.
c. br.	Connecting branch between intestinal tracts
cil.	Cilia.
c. t.	Connective tissue.
d.	Duct leading from posterior seminal chamber to penis.
d. c. m.	Dorsal circular muscles.
d. co.	Dorsal commissure.
d. ep.	Dorsal epithelium
d. l. m.	Dorsal longitudinal muscles.
d. v. m.	Dorso-ventral muscles.
e. cil.	External cilia.
e. ep.	External epithelium.
ep.	Epithelium.
g. at.	Genital atrium.
g. p.	Genital pore.
i. br.	Intestinal branches.
i. cil.	Internal cilia.
i. c. m.	Internal circular muscles.
i. c. s.	Intra-cellular spaces.
i. ep.	Internal epithelium.
i. l. m.	Internal longitudinal muscles.
in.	Intestine.
l. br.	Lateral nerve branches.
l. n. c.	Longitudinal nerve cord.
l. ph.	Lateral pharynges.
l. tr.	Lateral intestinal tract.
mes.	Mesenchyme.
mo.	Mouth.
m. s.	Muscular tube.
mus.	Muscular system.
o.	Ova.
oc.	Eye.
oc. c.	Clear parts of eye.
o. c. m.	Outer circular muscles.
oc. p.	Pigment of eye.
od.	Oviduct.
od. 2.	Tube formed by union of the two oviducts.
o. l. m.	Outer longitudinal muscles.
ov.	Ovary.
p. at.	Pharyngeal atrium.
p. c.	Posterior seminal chamber.
p. co.	Posterior commissure.
pe.	Penis.
ph.	Pharynx.
p. n. c.	Peripheral nerve cord.
p.s .	Penal sheath.
pt.	Partitions.
rh.	Rhabditi.
rh. c.	Rhabditi matrix cell.
r. ph.	Rudimentary pharynx.
s.	Sheath of sperm receptacle.
s-1. *s*-2.	Two different stages in spermatogenesis.
s. m. s.	Sub-muscular spaces.
sp.	Spermary.
sp'ga.	Spermatogonia.
sp. r.	Sperm receptacle.
sp'td.	Spermatids.
sp'za.	Spermatozoa.
ut.	Uterus.
ut. d.	Uterine duct.
v. b. w.	Ventral body wall.
v. c. m.	Ventral circular muscles.
v. co.	Ventral commissure.
vd.	Vas deferens.
vd. i.	Vasa deferentia within the sperm receptacle.
v. l. m.	Ventral longitudinal muscles.

PLATE 1

Fig. 1. Camera lucida drawing of a toto mount of Phagocata gracilis showing the general arrangement of the body regions and parts of the nervous, digestive, and reproductive systems, X 12.

Fig 2. Portion of a cross section showing the general structure of the worm, X 200.

Figs. 3-16. Series of cross sections taken at intervals throughout the entire body, X 18.

Fig. 3. Cross section close to the anterior margin of the body showing a large amount of sub-muscular spaces.

Fig. 4. Cross section through the eyes; part of the brain and anterior tip of the alimentary canal are also visible.

Fig. 5. Cross section through the center of the brain showing its two lobes and their connection.

Fig. 6. Cross sect on through the region of the ovaries.

Fig. 7. Cross section somewhat back of the ovaries showing the large anterior tract of the intestine; also intestinal branches, lateral nerve cords, oviducts, and testes.

Fig. 8. Cross section through region of the anterior or primary pharynx and beginning of the two lateral intestinal tracts.

Fig. 9. Cross section showing the three anterior pharynges and some of the partitions which are found in the pharyngeal cavity.

Fig. 10. Cross section through the region of the mouth showing sections of several pharynges, one of which is protruding from the mouth. Also shows how the intestine is pushed out toward the lateral walls of the body.

Fig. 11. Cross section through the posterior part of the pharyngeal atrium showing the uterus pushed forward dorsally over a part of the cavity. The oviducts and vasa deferentia are also visible.

Fig. 12. Cross section through the upper part of the sperm receptacle showing the cavity and sheath which surrounds this organ, the uterine duct, oviducts, vasa deferentia, spermaries, and part of the alimentary canal.

Fig. 13. Cross section through the posterior part of the sperm receptacle showing the anterior seminal chamber and the opening of the muscular tube into the cavity surrounding the receptacle.

Fig. 14. Cross section through the genital pore. The two lateral branches of the intestine are still visible.

Fig. 15. Cross section in the tail region showing a connecting branch between the two lateral branches of the intestine.

Fig. 16. Cross section in the extreme posterior region showing again the large sub-muscular spaces.

PLATE 2

Fig. 17A. Slightly enlarged drawing of a Phagocata as viewed against the light.

Fig. 17B. Various forms assumed by the worms when at rest.

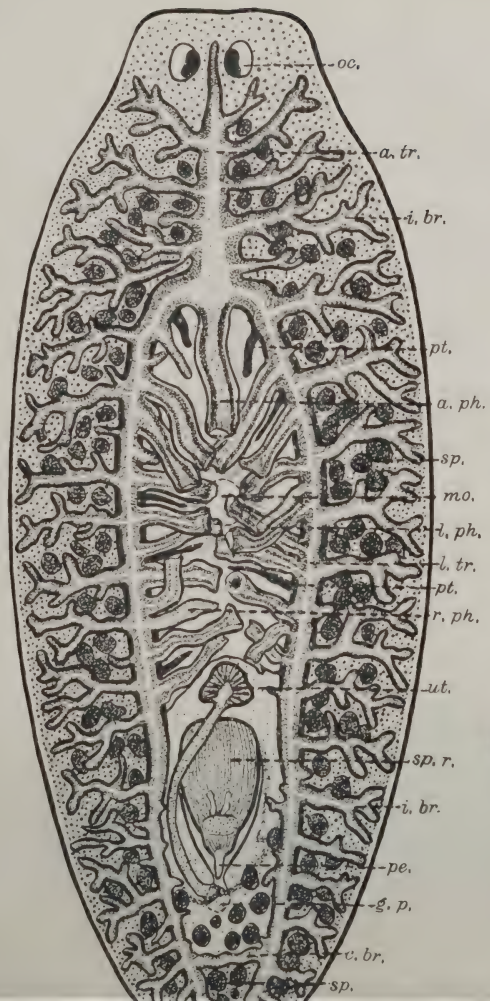
Fig. 17C. Ventral view showing several pharynges protruded from the mouth at one time; X 3.

Fig. 18. Portion of a transversesection of a spermary showing many of the details of spermatogensis, X 1000.
Fig. 19. Cross section of an ovary showing various stages in the development of the ova, X 350.
Fig. 20. Shows a characteristic cyst containing several worms attached to the under surface of the water, X 1.
Fig. 21. Individual cysts, X 1.
Figs. 22-24. Three longitudinal sections through the wall of a pharynx taken at intervals between the distal and proximal ends respectively, X 450.
Fig. 25. Frontal section of brain showing the two lobes, their anterior and posterior commissures, the branches to the head, and the beginning of the two main nerve trunks, X 225.
Fig. 26. Sagittal section through one of the brain lobes showing the outgoing nerves to the head and body, the connective tissue indentations, etc., X 450.
Fig. 27. Transverse section of brain showing general structure and division into dorsal and ventral commissures, X 225.
Fig. 28. Transverse section through an eye showing the dark part cut near the outer edge of the cup, and the fibrous condition of the outer or clear tissue, X 50.
Fig. 29. A frontal section near the ventral surface in the region of the genital pore showing the two peripheral cords and their interlacing branches, X 15.
Fig. 30. A yolk gland, X 250.
Fig. 31. Longitudinal section through one of the larger pharynges showing the general structure of the entire organ, X 87.
Fig. 32. Construction drawing of the reproductive system of Phagocata gracilis showing the position of the various parts as viewed from the side, X 70.
Fig. 33. Construction drawing of the reproductive system showing arrangement of the organs as viewed from above, X 70.
Fig. 34. Cross section of the uterine duct showing general structure, X 100.
Fig. 35. Cross section of one of the vasa deferentia in the region of the uterus, X 1000.
Fig. 36. Cross section of an oviduct showing its structure and relation to the surrounding tissue cells, X 1000.

PLATE 3

Figs. 37-48. A complete series of 30mu. frontal sections through the uterus, sperm receptacle, and penis, showing all details of structure, X 50.
Fig. 37. Section through the uppermost layers of the sperm receptacle.
Figs. 38-39. Show uterus and uterine duct cut about midway, and the beginning of the anterior seminal chamber.
Fig. 40. Shows beginning of muscular tube.
Fig. 41. Section through sperm receptacle showing ventral wall of the disappearing uterus, the uterine duct becoming circular in form due to its turning downward, and the first appearance of the enlarged ends of the vasa deferentia within the sperm receptacle.
Fig. 42. Similar to fig. 41, but showing in addition the posterior seminal chamber, and point of connection of the two oviducts.
Fig. 43. Section cut slightly lower than fig. 42.
Fig. 44. Typical frontal section through the sperm receptacle and penis.
Fig. 45. Shows connection between walls of the main receptacle sheath and those of the penal sheath. Also the left vas deferens and its point of entrance into the sperm receptacle, and the common oviduct emptying into the muscular tube.

Fig. 46. Section slightly lower than fig 45.
Fig. 47. Section through the point of entrance of the uterine duct and muscular tube into the genital atrium; also entrance of right vas deferens into sperm receptacle.
Fig. 48. Section through the genital atrium.
Figs. 49-64. Series of transverse sections through the sperm receptacle and the organs associated with it, X 50.
Fig. 49. Anterior end of receptacle showing its attachment to ventral wall of body.
Fig. 50. Section through point of entrance of vasa deferentia.
Figs. 51-52. Show relation of receptacle to sheath and uterine duct; also vasa deferentia and their corresponding internal ducts.
Figs. 53-54. Sections showing muscular tube, anterior seminal chamber, and enlargement of vasa deferentia within the sperm receptacle.
Figs. 55-56. Sections through the pinching off of muscular tube to form a complete duct; also union of the two vasa deferentia.
Fig. 57. Section showing the anterior seminal chamber.
Fig. 58. Section showing the connection between anterior and posterior seminal chambers, the looping back of the vasa deferentia, and the thickened wall of the uterine duct.
Fig. 59. Section through the posterior seminal chamber; the oviducts have converged so as to lie near the median line of the body.
Fig. 60. Section through the penis and the penal sheath.
Fig. 61. Section showing last vestiges of sperm receptacle sheath.
Fig. 62. Section showing union of oviducts.
Fig. 63. Section showing connection of muscular tube and uterine duct with the genital atrium.
Fig. 64. Section through point of entrance of the common oviduct into muscular tube.



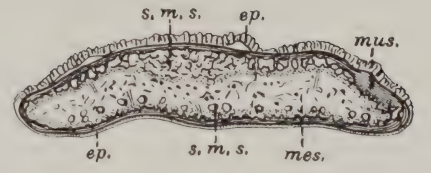


Fig. 3

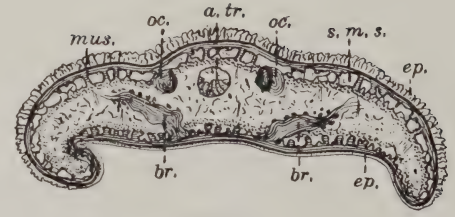


Fig. 4

Fig. 5

Fig. 6

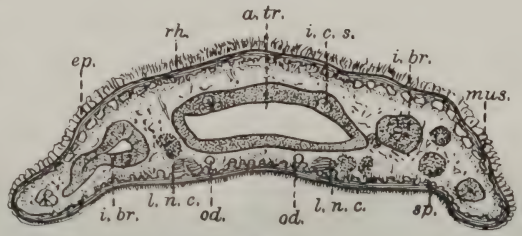


Fig. 7

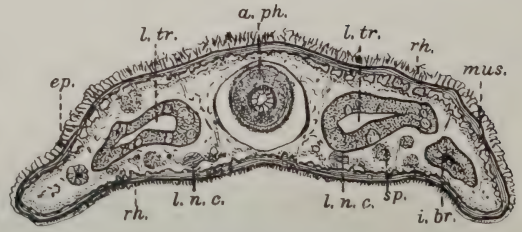
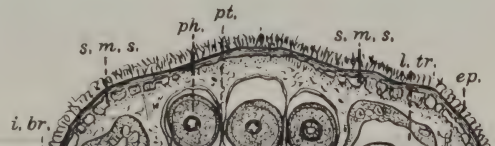
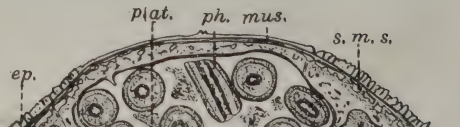


Fig. 8





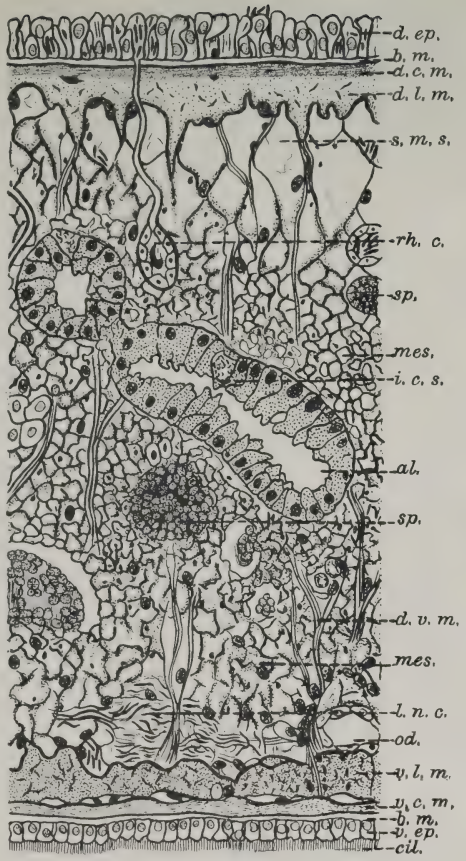


Fig. 2

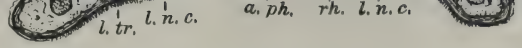


Fig. 1

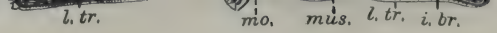
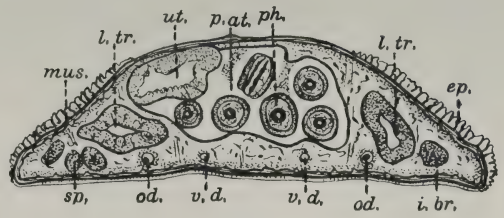


Fig. 9

Fig. 10



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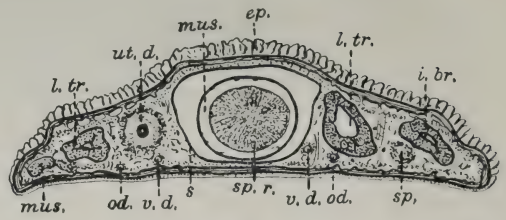

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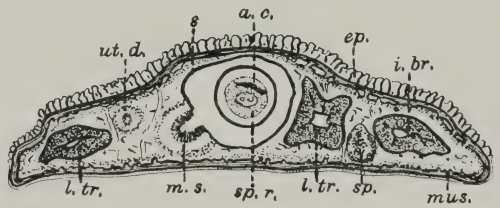

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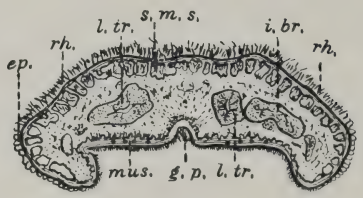


Fig. 14

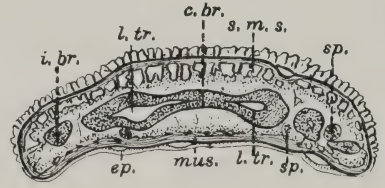


Fig. 15

Fig. 16

Plate I

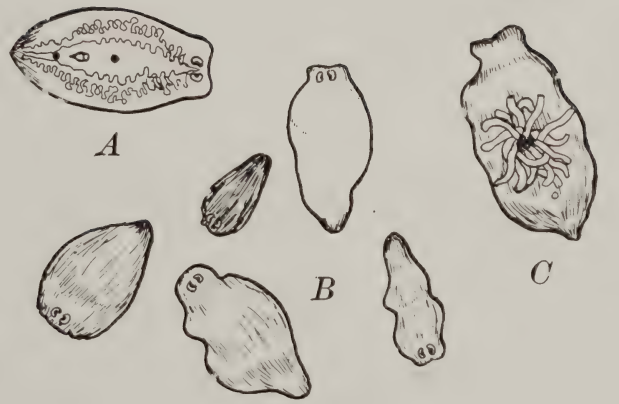
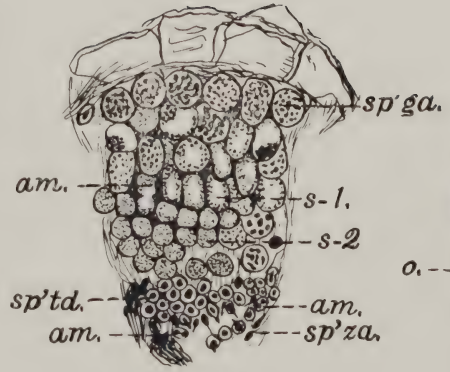


Fig. 17



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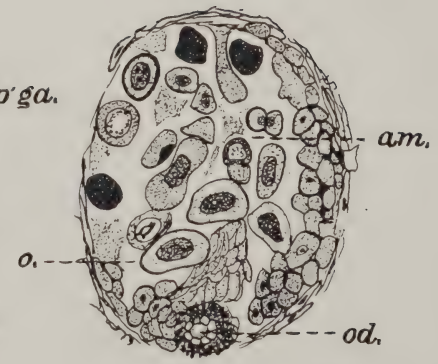


Fig. 19

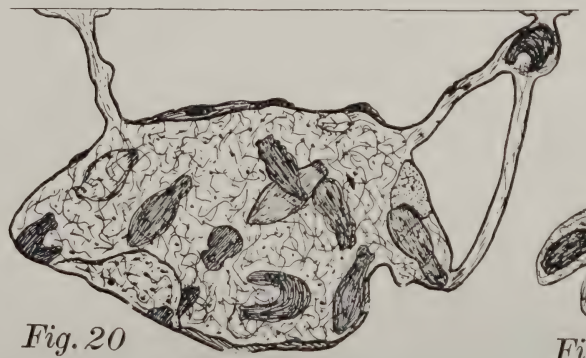


Fig. 20

Fig. 21

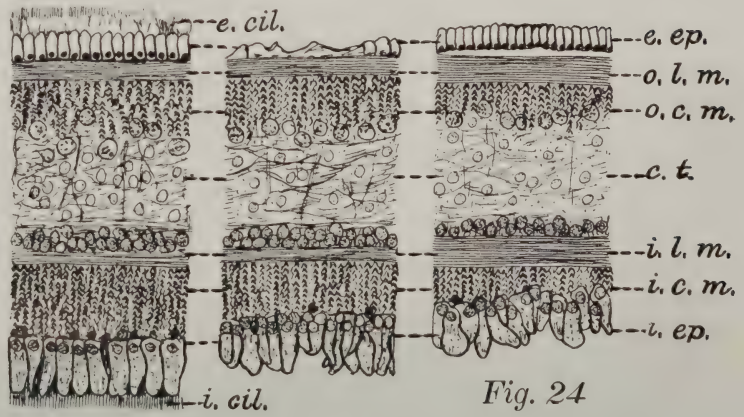
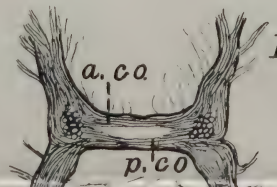


Fig. 22 Fig. 23 Fig. 24



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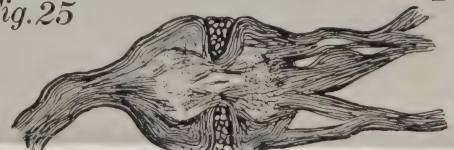
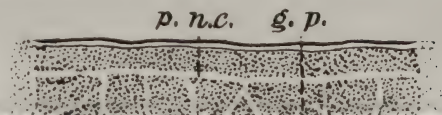




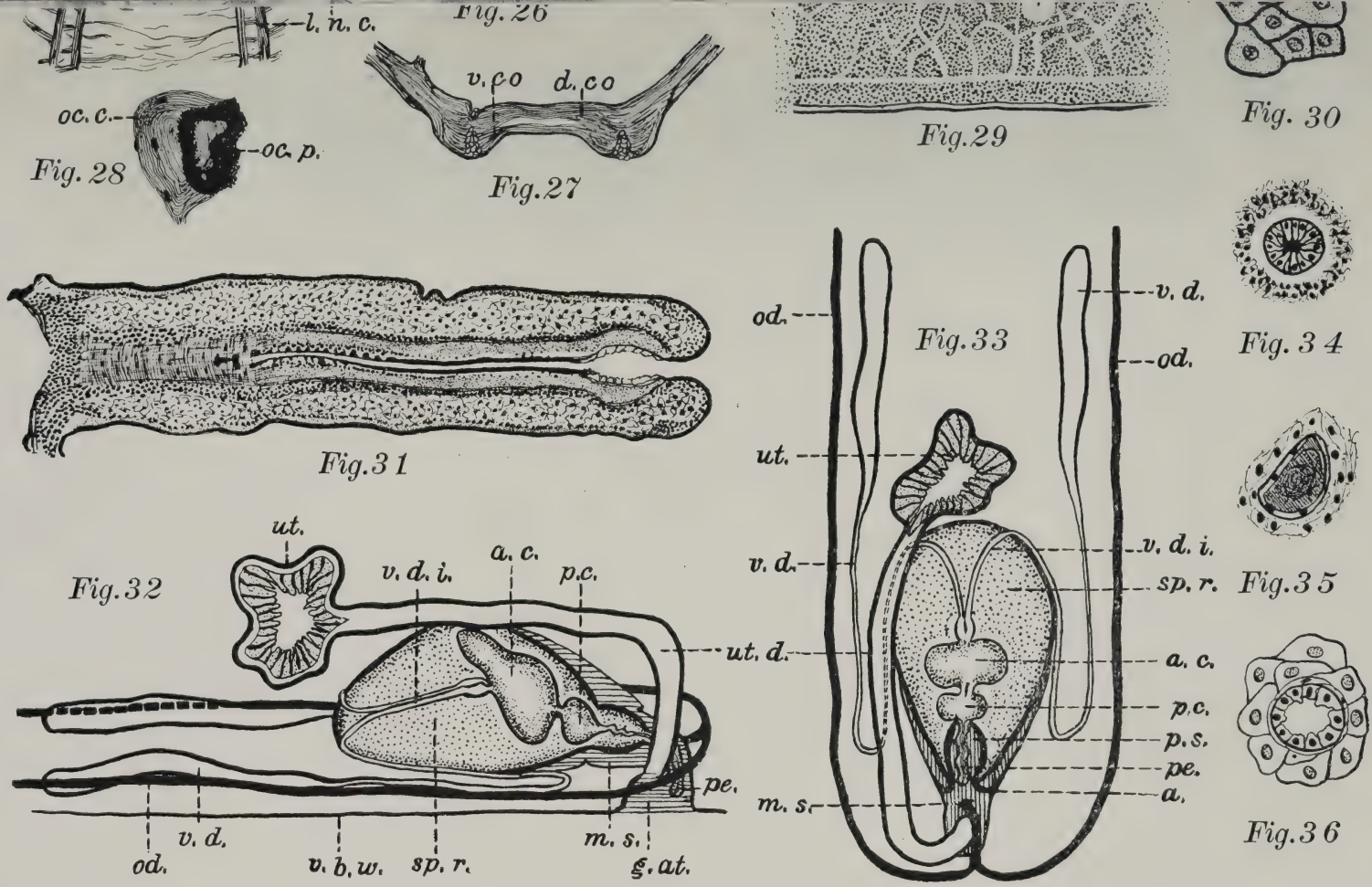

l. n. c.
Fig. 26
v. co
d. co
oc. c.
oc. p.
Fig. 28
Fig. 27
Fig. 29
Fig. 30
Fig. 31
Fig. 32
ut.
v. d. i.
a. c.
p.c.
ut. d.
pe.
v. d.
od.
v. b. w.
sp. r.
m. s.
g. at.
Fig. 33
v. d.
od.
ut.
v. d. i.
sp. r.
a. c.
p.c.
p.s.
pe.
a.
m. s.
Fig. 34
Fig. 35
Fig. 36

Plate II

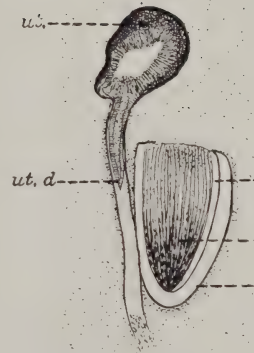
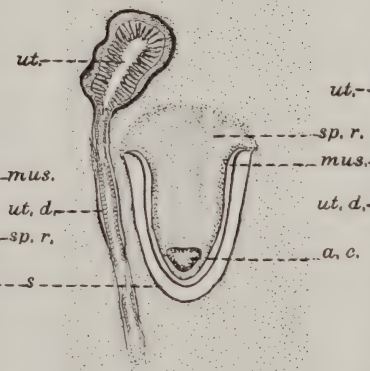


Fig. 37



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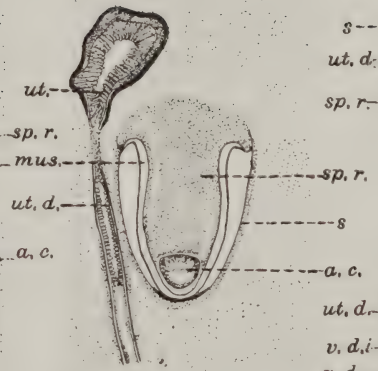


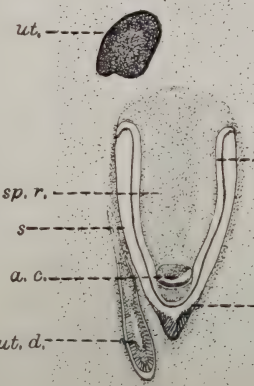
Fig. 39

Fig. 49

Fig. 50

Fig. 51

Fig. 52



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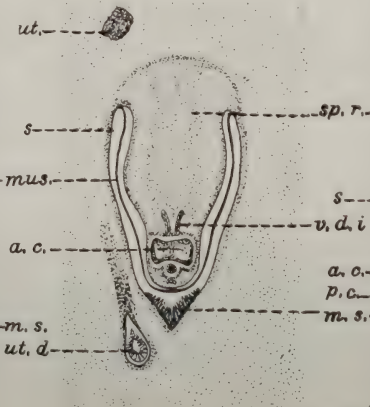
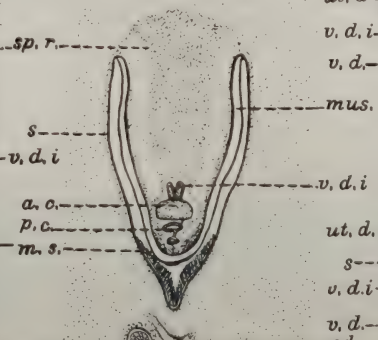


Fig. 41



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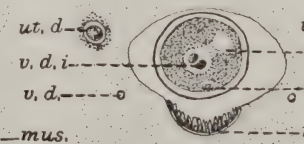

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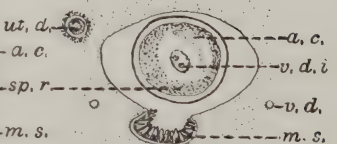

Fig. 54

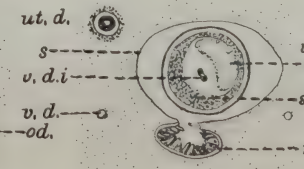

Fig. 55

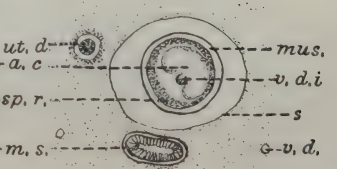

Fig. 56

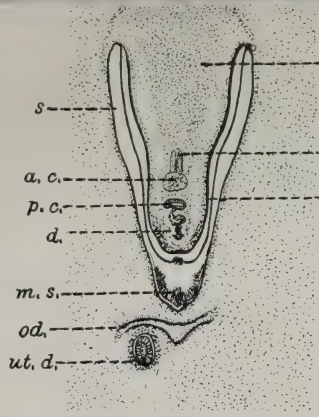

Fig. 4 3

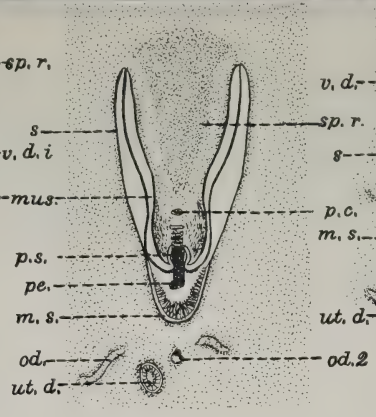

Fig. 4 4

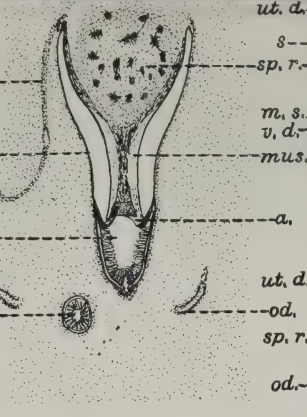

Fig. 45

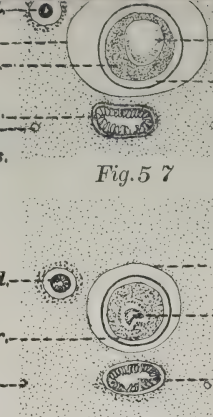

Fig. 5 7

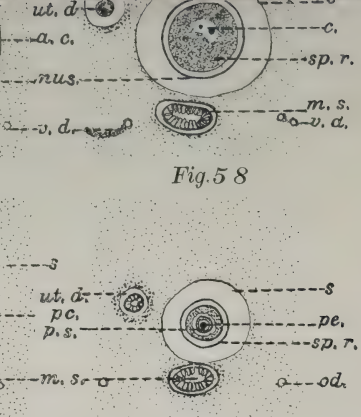

Fig. 5 8

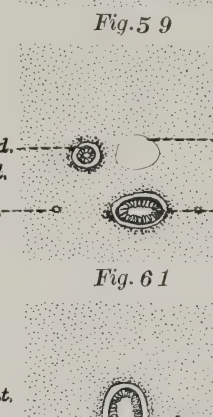

Fig. 5 9

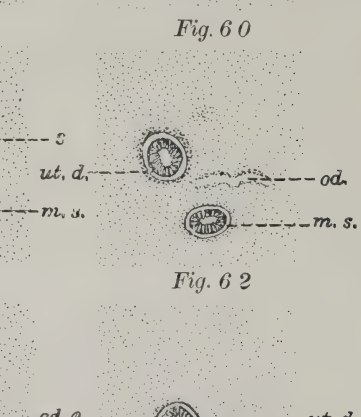

Fig. 6 0

Fig. 4 6

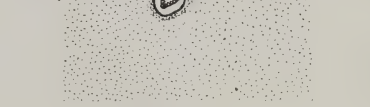

Fig. 4 7

Fig. 48

Fig. 6 1

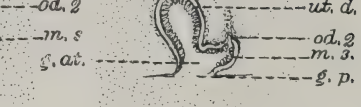

Fig. 6 2

Fig. 6 3

Fig. 6 4

Plate III

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